6.0 SUMMARY

The information and data reviewed for this study were of varying quality and detail. State agencies have been documenting fish kills within Galveston Bay for a number of years. As is the case with most public agencies, the quantity of work (i.e., number of fish kills reported) often exceeds the staff capabilities (e.g., the number of staff available to investigate fish kills). Therefore, agencies must establish priorities for fish kills to be investigated. For example, recently occurring fish kills with an easily identifiable cause and a responsible party may be thoroughly investigated. Whereas, a fish kill that was reported two weeks late and only affecting menhaden may not receive as high a priority given the available staff. The result is that there are a few fish kills where there is a great deal of information available and many more for which little data exist. A review of the available information then may lead to an inaccurate or incomplete picture of the human induced fish kills. Some events or causes may be thoroughly studied giving the impression that they have a major impact on aquatic life or only certain species are being affected. In contrast, other sources appear to have little effect on aquatic life or certain species appear to be unaffected by fish kills simply because they have not been studied.

In addition, scientific studies (e.g., impingement and entrainment, and seismic exploration) have been conducted to determine the impacts of various activities on aquatic life while other activities have been studied very little or not at all. This may leave these studied activities open to close scrutiny and criticism, either justly or unjustly, simply because they have been studied while the impacts from other activities remain unknown. In short, the results of this report are only as good as the quality of the available data.

Given this introduction, one may draw the following conclusions about human induced fish kills in Galveston Bay area. In comparison to other Gulf coast states during the 1980s, some of the highest concentration of fish kills were reported in Galveston and Chambers counties. In addition, the largest fish kill reported and the some of the highest concentrations of major fish kills (i.e., one million or more fish) occurred in the Galveston Bay area (i.e., Galveston and Chambers counties).

A review of state agency records revealed that, over the period of record (TWC/TDWR - 1970 to 1990; TPWD - October 1978 to June 1991), 321 fish kills were reported in the Galveston Bay. However, only 220 of these reports were reviewed for this study because they occurred within the defined study area, contained data about the number of fish killed, and were caused by human activity. During this period, a decreasing trend in the number of fish kills reported and the number of fish killed was observed.

Approximately 175.2 million fish were reported killed in the these 220 fish kills. The causes of 121 (55%) fish kills resulting in the deaths of more than 156 million (89%) fish were unknown. The remainder of fish killed and number of incidents reported were attributed to nonpoint sources (9.3 percent of fish killed and 20 percent of incidents reported) and point sources (1.4 percent of fish killed and 25 percent of incidents reported).

Within the point source category, the deaths of 96 percent of the fish were attributed to only seven sources: unknown spills at power generation facilities, an ocean dumping accident, STP by-passes, pipeline leaks and unknown activities at chemical manufacturing facilities, and detonation of explosives during seismic operations. Approximately 90 percent of the fish mortality attributed to point sources occurred in five segments: tributaries to Clear Lake and West Bay, San Jacinto Bay, West Bay, and Clear Creek. Size distribution data for fish killed by point sources were lacking. Of 244,118 fish for which length data were available, 99 percent were associated with one event in West Bay where TPWD was studying the impacts of a seismic exploration operation. Essentially all of the fish mortality caused by point sources occurred from May to October with peaks in May and September. Fish mortality due to point sources was less influenced by seasonal patterns than nonpoint sources.

Nonpoint source fish kills were mainly attributed to low dissolved oxygen concentrations either caused by the degradation of organic material or increased respiration at night by algae during bloom conditions. Factors contributing to nonpoint source pollution induced fish kills included nutrient and organic material accumulation (from both anthropogenic and natural sources) in contributing drainage areas; intensity, duration, and timing of runoff events; and other climatic conditions. Low dissolved oxygen levels resulting in fish mortality may be caused by large populations of algae induced by nutrient influx generated by runoff in combination with elevated solar intensity occurring in summer months. In addition, dissolved oxygen solubility decreases with increasing water temperature, such as occurs in summer months, resulting in less oxygen available for fish respiration.

A total of 16.3 million fish was killed by nonpoint sources. Ninety three percent (93%) of the mortality and 81 percent of the incidents were associated with undefined runoff events. Very little species identification and length-frequency data were available in this category. However, Gulf menhaden was the species most often affected. The areas where fish kills most often occurred due to nonpoint source events were Dickinson Bayou, tributaries to East Bay, San Jacinto Bay, and tributaries to Clear Lake. Nonpoint source related fish kills most often occurred from June through September with a peak in August. This trend coincided with weather conditions that were conducive to algal blooms leading to low dissolved oxygen fish kills.

One area for which there was a great deal of information available was the effect of cooling water operations (e.g., impingement, entrainment, and elevated temperatures) on finfish and shellfish in Galveston Bay. By far, the majority of information came from studies conducted at five HL&P generating stations (Robinson, Webster, Bertron, Deepwater, and Cedar Bayou) located within the Galveston Bay area. Those facilities that had the highest pumping rates usually impinged and entrained the most organisms (e.g., Robinson, Webster, Bertron, and Cedar Bayou stations). Higher species diversity was associated with those facilities at which sampling effort was the most intense. Intake velocity, usually greater than 1.1 fps, also influenced the number of organisms impinged. The only other facility withdrawing water from the Galveston Bay area that could have a major impact on finfish and shellfish in the bay was Sterling Chemical Company in Texas City. However, no impingement and entrainment studies have been conducted at this facility. Differences in species life history and distribution patterns, and quality and availability of habitat may have also affected species diversity and richness at each location, particularly at the Deepwater station.

The species most frequently affected by cooling water operations coincided with those that are probably most abundant in the bay. Species most commonly impinged at all HL&P stations included white shrimp, blue crab, Gulf menhaden, bay anchovy, sand seatrout, spot, and Atlantic croaker. Species less frequently impinged at all stations but still in large numbers included brown shrimp, sea catfish, and striped mullet. Commercially and recreationally important species such as spotted seatrout, black drum, red drum, and southern flounder were infrequently impinged and only in small numbers.

Organisms impinged or entrained were generally postlarval crustaceans and juvenile fish that could not swim faster than the intake velocities at the generating stations. Larval fish and fish eggs were also entrained at these facilities. The most abundant included naked gobies, Gulf menhaden, bay anchovy, and comb-tooth blennies. The sizes most frequently impinged varied by station.

The numbers of organisms impinged usually coincided with the life history of the organism. For example, peak periods of impingement for Gulf menhaden coincided with the peak periods of recruitment in March and April. For other species such as blue crab, no clear peaks were observed. Fewer organisms were impinged during the warmer months, May through August.

Short and long-term survival rates were studied at the Robinson and Cedar Bayou stations. Short-term injury rates were higher during the summer months when fewer numbers of fish were present in the intake canal at the Robinson station. Most injuries of impinged organisms were primarily of an external nature. This included predation by blue crabs. Injury rates were generally higher at units with higher pumping rates (e.g., Units 3 and 4 at the Robinson station).

Overall probabilities of survival, excluding the effects of elevated temperatures in discharge canals which generally occurred from May through August, were calculated for several species impinged at the Robinson station. Crustaceans (brown shrimp and blue crab) had overall probabilities of survival greater than 0.70 (greater than 0.45 for white shrimp) at Units 1 and 2. Overall probabilities of survival were lower at Units 3 and 4 (i.e., greater than 0.30 for white and brown shrimp and greater than 0.50 for blue crab). Overall probabilities of survival for fish were much lower than for crustaceans. Most fish had probabilities less than 0.10; however, spot had probabilities of 0.25 at Units 1 and 2 and 0.04 at Units 3 and 4.

The effects of impingement, passage through a fish pump, and long-term (i.e., 96-hr) survival were evaluated at the Cedar Bayou station. Survival rates immediately after impingement at the Cedar Bayou station were much greater than those reported at the Robinson station. Crustaceans (i.e., white shrimp, brown shrimp, and blue crab) had the highest immediate survival rates (> 95%). Most of the abundant fish had survival rates greater than 70% with many such as Gulf menhaden, spot, and southern flounder, greater than 90%. The most sensitive species was the least puffer with an immediate survival rate of 44%.

Survival rates immediately after impingement and passage through the fish pump were generally greater than 70% with for all species with crustaceans (i.e., white shrimp, brown shrimp, and blue crab) among the highest (>84%). The most sensitive species were red drum (0%) and black drum (50%), but these results were suspect because the sample sizes were very small. Of the six species tested for long-term effects of impingement and passage through the fish pump, sand seatrout was the most sensitive with 13% survival. The remaining species tested (i.e., spot, Atlantic croaker, blue crab, white shrimp, and brown shrimp) had survival rates greater than 50%. Again, crustaceans were hardier than fish.

Only six species were used in the heat-shock studies. No sand seatrout survived. Spot, white shrimp, and brown shrimp survival rates ranged between 19% to 27%. Atlantic croaker survival rates were 40%, while blue crab was the hardiest species tested with a 66% survival rate. Overall, survival rates for all species decreased from impingement to passage through the fish pump to placement in the discharge canal.

Studies at the Cedar Bayou station documented that stress and injury caused by impingement and entrainment reduced the organisms' ability to deal with elevated temperatures in the discharge canal. Studies at the Robinson station indicated that the effects of elevated temperatures began at 30 C. At this temperature, Gulf menhaden did not survive in the discharge canal. Atlantic croaker were repelled from the discharge canal when water temperatures were greater than 32 C. Bay anchovy, sea catfish, sand seatrout, and spot avoided temperatures greater than 35 C. Decreased survival for larval blennies was observed at the Robinson station when water temperatures reached 36.7 C with no individuals collected in the discharge canal when temperatures exceeded 38.4 C. At the Cedar Bayou station, blue crab survival decreased when discharge canal water temperatures exceeded 33.3 C with no survival when temperatures were greater than 36 C. No brown shrimp or white shrimp survived when discharge canal water temperatures were greater than 33.3 C at Cedar Bayou. At the Robinson station, fish egg survival ranged from 11.3 percent to 54.3 percent when discharge canal temperatures ranged from 38.4 C to 38.9 C. However, no fish eggs were found alive in cooling towers when temperatures ranged from 32.2 C to 34.7 C, indicating fish eggs were more sensitive to physical impacts from bouncing and splashing in the towers.

There were some beneficial effects from the discharge of heated effluent. During the late winter and early spring, rapid growth of young-of-the-year spot was observed in the Robinson canal. Also, large numbers of fish are found congregated in the canal and near the outfall during the winter months.

Over 87 million organisms weighing more than 447,000 kg were estimated to be impinged during 1978 when data were available for all the five HL&P station on Galveston Bay. During this year, the most organisms estimated impinged occurred at the Cedar Bayou station, followed by the Robinson station. Similar numbers of organisms were estimated impinged at the Bertron and Webster stations. The fewest numbers were estimated impinged at the Deepwater station. The total number and weight of organism estimated impinged at the Cedar Bayou station showed a general decreasing trend from 1974 to 1980.

The available literature demonstrated that only a portion of impinged organisms die. Organisms were exposed to temperatures exceeding thermal tolerances (beginning at 30 C for menhaden) only from May through August which corresponded to the time when fewer organisms were impinged. Therefore, survival rates were greater during the time period when more organisms were impinged. Finally, more crustaceans were impinged by number and weight than finfish other than menhaden. Survival studies demonstrated that crustaceans (white shrimp, brown shrimp, and blue crab) generally had higher survival rates than finfish at HL&P stations.

Therefore, the organisms most frequently impinged had higher survival rates. In contrast, these comparisons did not include the estimated number of organisms impinged from the only other facility identified that could possibly impinge the magnitude of organisms as the HL&P facilities.

A recent study analyzed CPUE trends of 14 species in Galveston Bay, and the authors concluded that the Galveston Bay estuary was still a very viable ecosystem. However, of the CPUEs analyzed for 14 species, only blue crab and white shrimp showed declining trends in CPUE. The size classes of blue crabs showing a declining trend were similar to size classes impinged at HL&P facilities. The most critical size classes for white shrimp were impinged most frequently at the Robinson and Deepwater facilities. Unfortunately, no overall impingement trend data were available for HL&P facilities to compare to the CPUE trend study. However, more than 50% of blue crab and white shrimp estimated impinged at HL&P facilities during 1978 were impinged at the Cedar Bayou station, and there were eight years of impingement data collected at this station. While no size ranges were reported for crustaceans at the Cedar Bayou station, no obvious trends were observed for blue crab impingement and a decreasing trend was observed in the number of white shrimp impinged from 1975 to 1980.

Recommendations

While non-fishing human induced fisheries mortalities can be quantified, the impact of these mortalities on overall finfish and shellfish populations remains unknown. In the absence of any known standing stock estimates for Galveston Bay, JN used the TPWD report on CPUE trends in Galveston Bay. Unfortunately, the fish kill and impingement data evaluated in this report were not directly comparable to CPUE data. As a result, impacts of non-fishing human induced mortalities of fisheries populations could only be loosely inferred. Before additional or follow-up studies are undertaken, methods should be developed by fisheries specialists to determine or estimate standing stocks. Once methods are developed to estimate fisheries standing stocks in Galveston Bay, fisheries experts can use the results of this report to recommend additional data that should be collected by fish kill investigators to evaluate impacts to fisheries populations.

While the number of fish kills reported to agencies is beyond their control, the quality of investigations and the amount of data gathered are certainly factors agencies can control. As a result, JN recommends that all agencies collecting data should use similar investigation procedures such as the American Fisheries Society fish kill investigation procedures. At the minimum, all organisms killed should be identified to species. The total number killed by inch group should also be estimated. Intensive efforts (e.g., water quality testing, fish autopsies, etc.) should be conducted for each fish kill to identify the cause of fish mortalities. Agencies should coordinate their efforts to minimize duplication of effort. In addition, agency fish kill investigation programs should be adequately funded and staffed to support these efforts. Many of these recommendations are already being used by state agencies. However, agency staff, particularly new employees, should be continually trained in these procedures.

One of the most obvious results of this study was that, for the years data were available, millions of finfish and shellfish were impinged at the five HL&P generating stations located on Galveston Bay. Only one other facility was identified that might pump the quantities of water with similar intake velocities as the HL&P power plants. While impingement data were available for at least one year at each of the facilities, entrainment data were not available for all facilities. In addition, multi-year impingement data were available for only the Cedar Bayou station. While the impacts of impingement and entrainment to finfish and shellfish populations in Galveston Bay remain unknown, impingement and entrainment remain the single largest source of impacts identified by this study. Additional multi-year impingement and entrainment studies should be conducted at these facilities to determine how they impact finfish and shellfish populations in Galveston Bay. However, these studies should not be initiated until a study design is developed that would establish a direct cause and effect relationship between mortalities due to impingement and entrainment and its effects finfish and shellfish populations in Galveston Bay.